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Feasibility Study of Biomass Gasification Integrated with Reheating Furnaces in Steelmaking Process

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Abstract

This paper investigates the integration of biosyngas production, reheating furnace and heat recovery steam cycle, in order to use biosyngas directly as fuel in the furnace. A system model was developed to evaluate the feasibility of the proposed system from the perspective of heat and mass balance. To particularly study the impacts of fuel switching on the heating quality of the furnace, a three-dimensional furnace model considering detailed heat transfer processes was embedded into the system through an Aspen Plus™ user defined model. The simulation results show that biosyngas is suitable for direct use as fuel for reheating furnaces. Should CO_2 capture be considered in the proposed system, it has a potential to achieve the capture without external energy input which results in so-called negative emissions of CO_2.

Keywords: biomass, gasification, reheating furnace, biosyngas, heat recovery

1. Introduction

Under the context of a low-carbon economy, energy intensive industries have an essential role to play in delivering the UK's transition to a low-carbon economy, as well contributing to economic growth and rebalancing the economy. The iron and steel industry is one of the largest industrial emitters of CO_2 in the UK as it relies on carbon, usually fossil fuels, as a chemical reductant resulting in significant amounts of process related carbon emissions for integrated sites. Not only that but also intermediate steel products such as slabs, blooms or billets (known as the stock or furnace load) need to experience a reheating process (in a reheating furnace) to reach a desired mean discharge temperature and temperature uniformity prior to subsequent hot forming or rolling process. The reheating process is energy intensive and its carbon emission accounts for 67% of total non-process related carbon emissions [1]. To achieve CO_2 mitigation, in addition to carbon capture fuel switching is also imperative [2].

Biomass as substitution of fossil fuels and reducing the need for reductant agents has been considered as one of the ways the iron and steel industry can achieve its goals of reducing CO_2 emissions in the short to medium term [3]. Particularly, the potential for biomass in reheating furnaces has been explored previously in terms of energy efficiency by optimizing the biomass pretreatment conditions [4]. Although the required process conditions of the reheating furnace can be achieved by using biosyngas from the perspective of heat and mass balance, it is still necessary to further demonstrate whether the combustion of biosyngas can meet the heat transfer requirements of the reheating process. That is because biosyngas typically has a low energy density and therefore a low flame temperature, which limits its use in high temperature processes. Therefore, combustion systems must be designed to increase the flame temperature by either preheating of reactants (fuel and oxidant) or reducing the air-fuel ratio. On the other hand, the gas emissivity of the product of biosyngas combustion is higher than natural gas combustion, due to the high water vapor level in fumes. The radiant heat transfer to the furnace load with biosyngas combustion products will be higher even if an equivalent temperature is reached. The necessity of system design and the inherent

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characteristics of combustion make it necessary to study fuel switching from a trans-dimensional perspective, that is, considering both the energy efficiency of the entire system (zero dimensional) and the heating quality of the furnace (three dimensional) in the modelling.

2. System description

In view of above, in this study we explored the system integration of reheating furnace with biomass gasification and waste heat recovery from a trans-dimensional perspective. As shown in Figure 1, in this system, first the raw biomass enters the fluidized bed gasifier and undergoes processes such as drying, pyrolysis, and gasification in sequence. The generated biosyngas is directly fed to the reheating furnace as a fuel. In order to recover the condensation heat of the raw biosyngas and the waste heat from the flue gas, a heat recovery (HR) steam cycle is integrated into the system. The motive steam generated by the steam cycle drives the generator to generate electricity while the steam exhaust is used as the gasification agent of the gasification process. The reheating furnace studied is a pilot-scale reheating furnace located at Swerim AB, Sweden [5], as shown in Figure 2, with a production capacity of 3 tonne/hr and a target heating temperature of 1250 °C. The furnace has an effective length of 9 m and width of 2.2 m. The furnace height varies depending on the furnace zone which is typically 1.8 m from the hearth skids in a combustion zone. A total of 17 slabs (0.155m×0.4m×1.7m, 7800kg/m^3) are regularly arranged on the walking beams at each instant. All parameters of the fluidized bed gasifier and HR steam cycle are set to ensure normal operation of the reheat furnace. Table 1 lists the proximate and ultimate analyses of the raw biomass.

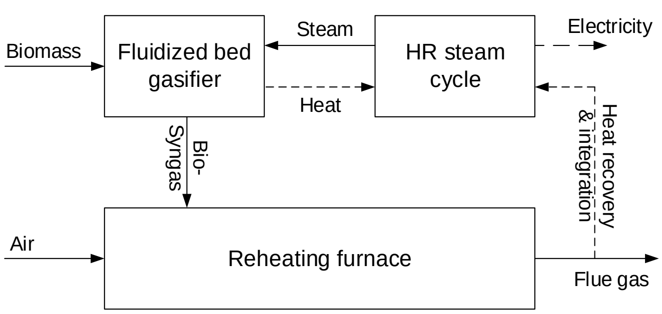


Figure 1. A schematic diagram of system integration (solid line: mass flow; long dash line: electricity; short dash line: heat flow)

3. Model development

The three main processes characterizing the integration of biosyngas production, reheating process and HR steam cycle have been modelled using Aspen Plus™ commercial simulation software. The process flowsheet designed (see Figure 3) can be used to calculate mass and energy balances, emissions, and the chemical compositions of products and by-products simultaneously.

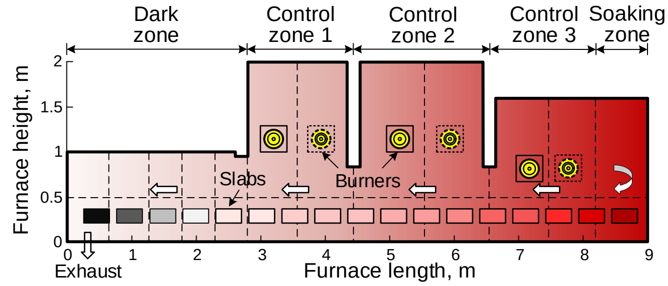
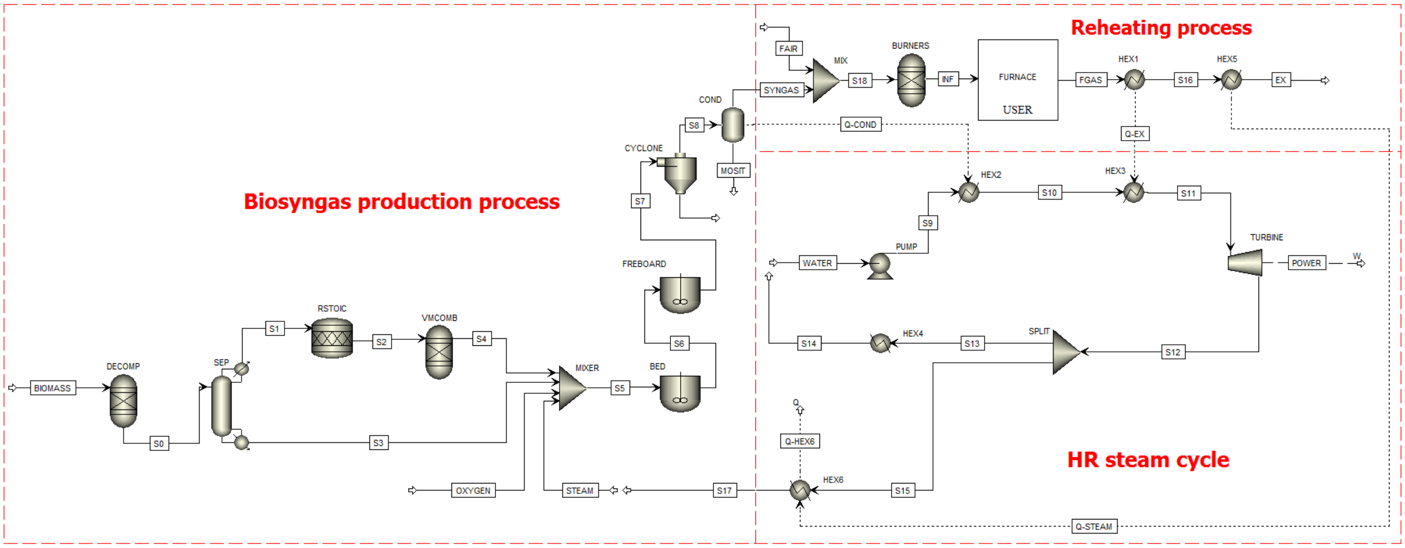


Figure 2. Outline of the pilot-scale reheating furnace

Table 1. Proximate and ultimate analyses of the raw biomass [6]

Moisture content (wt%)	8
Proximate analysis (wt%, dry basis)	
Volatile matter	82.29
Fixed carbon	17.16
Ash	0.55
Ultimate analysis (wt%, dry basis)	
C	50.54
H	7.8
O	41.11
N	0.15
S	0.57
Average particle size (mm)	0.25-0.75
Char density (kg/m^3)	1300

The previous work of *Hu et al.* [7] had described the implementation of Aspen Plus reactor modules for fluidized bed modelling in detail which will not to be repeated here. It should be noted that the reaction kinetics were necessarily updated to accommodate the gasification processes such as pyrolysis, volatile matter combustion, and bio-char steam gasification in this study [6]. In order to particularly study the impacts of fuel switching on the heating quality of the furnace while evaluating the energy efficiency of the entire system, a three-dimensional furnace model considering detailed heat transfer processes was developed [8] and embedded into the system through an Aspen Plus user defined model. In the simulation, the furnace model can calculate the slab heating profile and the furnace temperature distribution based on the retrieved zero-dimensional stream data from the upstream and then pass the stream data of the flue gas to the downstream. A simple steam cycle was employed to evaluate the feasibility of recovering waste heat from the biosyngas condensation and flue gas to generate motive steam, and part of the exhaust steam after power generation is used for steam gasification. Although there are more complex steam cycles that are more efficient [9], this is beyond the scope of this paper and they therefore are not employed in this study.



4. Results and discussion

Table 2 lists the system simulation input parameters and key results. The biosyngas produced in the proposed system has a net heating value of 13.60 MJ/kg, which is mainly composed of carbon monoxide and hydrogen, and contains 7.13% of water vapor if condensed at 45 °C. By recovering the condensation heat of the raw biosyngas and the waste heat from the flue gas, 2055 kg of motive steam can be produced per hour, which can drive the steam turbines to produce 0.39 MW of electrical energy.

Table 2. Input parameters and results of the system simulation

<u>*Input parameters*</u>	
Biomass input, kg/hr	258
Steam to biomass ratio, -	1.0
Carbon conversion efficiency, -	0.9
Excess O_2, mol%	3.0
Motive steam, bar/°C	135/470
Flue gas temperature, °C	100
<u>*Results*</u>	
Gasification temperature, °C	850
Biosyngas composition, mol%	
O_2	0.27
CO	33.20
H_2	50.06
CO_2	9.24
H_2O	7.13
Biosyngas heating value, MJ/kg	13.60
Turbine generation, MW	0.39
Make-up water, kg/hr	258
CO_2 emission, kg/hr	403

The performance of the reheating furnace requires further examination. Figure 4 shows the comparison of the predicted top, centre, and bottom temperature profiles of the slab to the desired heating profile. The desired heating profile comes from an actual trial using fuel-oil as a fuel, which can be used as a reference to evaluate heating performance of the reheating furnace. As can be seen from this figure, in general, the predictions were in good agreement with the desired heating profile. However, slight over-prediction is still observed around the heating zones (Control zones 1 and 2). This is believed to be due to the effect of oxide formation on the slab surface which was not taken into account. Oxide scales covering the slab surface have a much lower thermal conductivity, thus the model over-predicts the slab temperatures.

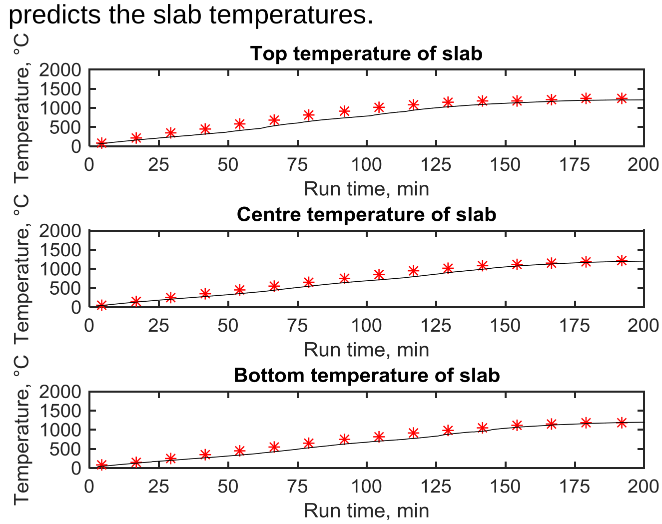


Figure 4. Comparison of the predicted slab heating profile with the desired heating profile (red symbol: predicted profile; black line: desired profile)

Figure 5 further shows the gas temperature profile along the furnace length. The furnace can reach the set-point temperature in each control zone. The gas temperature of the furnace upper-layer was slightly higher than that of the furnace bottom-layer given the top-fired nature of the furnace. The bottom-layer gas temperature at furnace length of zero is the flue gas temperature of the furnace, which is about 490 °C. The result is consistent with the actual trial using fuel-oil as a fuel.

Figure 5. Gas temperature profile along the furnace length

As mentioned previously, the motivation of using alternative fuel in rehearing furnaces is to achieve CO_2 mitigation. The proposed integration system is likely to be further integrated with CO_2 capture processes. No matter what capture approach is used, an unavoidable issue is the extra energy consumption due to carbon capture. According to the state of the art of post-combustion capture with chemical absorption, the extra energy consumption for absorbent regeneration is 3.35 MJ/kg CO_2 [10]. To capture the CO_2 emitted from the proposed system will need extra energy of 0.38 MW. The simulation results show that the electricity generation of the HR steam cycle can fully compensate for the extra energy consumption. Last but not the least, if biosyngas is used as a fuel, the reheating furnace with post-combustion CO_2 capture has a potential to result in so-called negative emissions of CO_2 since bio-energy sources extract CO_2 from the atmosphere whilst growing together achieving bio-energy with carbon capture and storage (BECCS) [11].

5. Conclusions

In this paper, system integration of biosyngas production, reheating furnace, and heat recovery steam cycle is proposed, and the thermal performance of reheating furnace using biosyngas as fuel is analysed. The results show that the proposed system is technically feasible from the perspective of heat and mass balance and the reheating furnace can work well to heat the slab to the target temperature. Should CO_2 capture be considered in the proposed system, the electricity generation of the HR steam cycle can fully compensate for the extra energy consumption due to CO_2 capture. Although the proposed system is technically feasible, the optimum operating conditions must be studied to further enhance the system efficiency.

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Reference

[1] Steinboeck A, Wild D, Kugi A. Energy-efficient control of continuous reheating furnaces. vol. 46. IFAC; 2013.

[2] Fu J xun, Tang G hao, Zhao R jie, Hwang W sing. Carbon reduction programs and key technologies in global steel industry. J Iron Steel Res Int 2014;21:275–81.

[3] Suopajärvi H, Kemppainen A, Haapakangas J, Fabritius T. Extensive review of the opportunities to use biomass-based fuels in iron and steelmaking processes. J Clean Prod 2017;148:709–34.

[4] Gunarathne DS, Mellin P, Yang W, Pettersson M, Ljunggren R. Performance of an effectively integrated biomass multi-stage gasification system and a steel industry heat treatment furnace. Appl Energy 2016;170:353–61.

[5] Hu Y, Tan CK, Niska J, Chowdhury JI, Balta-Ozkan N, Varga L, et al. Modelling and simulation of steel reheating processes under oxy-fuel combustion conditions – Technical and environmental. Energy 2019:(under review).

[6] Nikoo MB, Mahinpey N. Simulation of biomass gasification in fluidized bed reactor using ASPEN PLUS. Biomass and Bioenergy 2008;32:1245–54.

[7] Hu Y, Wang J, Tan CK, Sun C, Liu H. Coupling detailed radiation model with process simulation in Aspen Plus: A case study on fluidized bed combustor. Appl Energy 2018;227:168–79.

[8] Hu Y, Tan CK, Broughton J, Roach PA. Development of a first-principles hybrid model for large-scale reheating furnaces. Appl Energy 2016;173:555–66.

[9] Dincer I, Demir ME. Steam and Organic Rankine Cycles. vol. 4–5. 2018.

[10] Zhang W, Liu H, Sun Y, Cakstins J, Sun C, Snape CE. Parametric study on the regeneration heat requirement of an amine-based solid adsorbent process for post-combustion carbon capture. Appl Energy 2016;168:394–405.

[11] Obersteiner M, Azar C, Kauppi P, Möllersten K, Moreira J, Nilsson S, et al. Managing Climate Risk. Science (80-) 2001;294:786 LP – 787.